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THE EFFECT OF VALVE CLEARANCE ON KNOCK-LIMITED PERFORMANCE AND ENGINE COOLING

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

THE EFFECT OF VALVE CLEARANCE ON KNOCK-LIMITED PERFORMANCE AND ENGINE COOLING

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SUMMARY

Tests were conducted to investigate the effect of valve clearance on valve-lift diagrams, knock-limited performance, and engine cooling. Static and running valve-lift diagrams for a single front-row cylinder mounted on a CUE crankcase were compared with static valve-lift diagrams for the multicylinder engine. Knock-limited and cooling performance of the single-cylinder engine with several cold valve clearances was compared with that of the multicylinder engine as determined in flight. The effect of valve clearances on cylinder temperatures and fuel consumption was investigated in cooling tests at constant power and constant fuel-air ratio.

The results of the investigations indicated that the knock-limited and cooling performance of the single-cylinder engine and the multicylinder engine matched when valve clearances for the single-cylinder engine gave running valve-lift diagrams similar to static valve-lift diagrams for the multicylinder engine. Knock-limited charge-air flow of the single-cylinder engine was lowered as much as 26 percent by changing the valve clearances. In cooling tests at constant power and constant fuel-air ratio the same change in valve clearances that lowered the knock-limited charge-air flow reduced the indicated specific fuel consumption but did not change the cylinder temperatures.

INTRODUCTION

At the request of the Army Air Forces, Air Technical Service Command, the NACA is conducting an investigation at the Cleveland laboratory to evaluate high antiknock hydrocarbons as components of aviation fuel. In this program, tests are being conducted on a single cylinder of a radial aircraft engine and on the complete engine on a test stand and in flight.

Preliminary tests show that under presumably the same test conditions the knock-limited performance of the single-cylinder engine was considerably higher than that of the multicylinder engines either in flight or on the test stand. A number of engine variables were examined to determine the reasons for the high knock limit with the single-cylinder engine. Valve clearance was found to be an important variable. Valve clearance affects performance chiefly through the valve opening and closing events. The opening of the intake valve and the closing of the exhaust valve are probably of greatest importance inasmuch as valve overlap affects the cylinder scavenging process. Differences in the cam-follower mechanisms and the thermal expansions of the crankcases of the single-cylinder and multicylinder engines are known to cause dissimilar valve operating clearances.

Tests were conducted during the early part of 1945 on a single-cylinder engine to determine the effect of valve clearance on static and running valve-lift diagrams and on knock-limited and cooling performance. Static valve-lift diagrams were also obtained on a multicylinder engine. For comparison, unpublished knock-limited data on the performance of a multicylinder engine in flight are included.

APPARATUS AND PROCEDURE

A Pratt & Whitney R-1830-94 front-row cylinder was tested in a single-cylinder setup, arranged as shown in figures 1 and 2. Cylinder temperatures were measured by iron-constantan thermocouples located at the rear spark-plug boss, the front spark-plug boss, the rear middle barrel, and the rear flange. Mixture temperature was indicated by an unshielded iron-constantan thermocouple in the center of the intake pipe.

The Pratt & Whitney R-1830-94 engine used in the flight tests in a B-24D airplane had thermocouples installed at the same locations on all cylinders as for the single-cylinder engine. Cylinder and mixture temperatures were determined from an average of the 14 cylinders. The cooling-air pressure drop for the multicylinder engine was measured by total-pressure tubes in front of the cylinder and static-pressure tubes behind. For both the single-cylinder and the multicylinder engines, the cooling-air pressure drop was multiplied by σ, the ratio of the air density ahead of the cylinder to a standard air density of 0.0765 pound per cubic foot.

The fuel used in all the tests was 28-R. Knock was detected by magnetostriction pickup units, which were installed in the cylinder heads at the same location for both the single-cylinder and the multicylinder engines.

Static valve-lift diagrams for the single-cylinder and multicylinder engines were obtained by manually turning the engine over and measuring valve movement with a dial indicator. Running valve-lift diagrams were obtained for the single-cylinder engine with an instrument developed by the Instrument Division of the NACA at Cleveland. The valve lift as recorded by the instrument was enlarged 10 times; the accuracy of the diagrams was estimated to be ± 0.002 inch valve lift and $\pm 0.5^{\circ}$ crankshaft rotation.

The valve-lift recording instrument operated as follows: The valve-lift diagram was produced by sparks jumping from a stylus through paper wrapped on a drum rotated at crankshaft speed. The stylus was moved axially along the drum by a screw driven by an electric motor. This motor was synchronized with another that moved an electric contact in a pickup unit mounted over the rocker-box cover. A rod fastened to the valve-spring washer projected through the rocker-box cover into the pickup unit. The portion of the rod in the pickup unit contained a contact, which registered with the motor-driven contact twice during each engine cycle. These contacts in conjunction with an electronic circuit produced a single intense spark at the stylus each time the contacts closed. The synchronized motors were controlled by limit switches as well as by the operator. A complete valve-lift diagram could be obtained in about 20 seconds.

The engine operating conditions held constant in single-cylinder tests to investigate valve-lift diagrams, knock-limited performance, and cylinder cooling are presented in the following table:

Engine conditions	Valve-lift diagrams	Knock-limited performance	Cylinder cooling
Engine speed, rpm	2250	2250	2250
Inlet-air pressure, in. Hg abs.	36	Varied	Varied
Inlet-air temperature (before vaporization tank), °F	210	270	210
Fuel-air ratio	0.075	Varied	0.075
Mixture temperature, °F	150	Varied	Varied
Spark advance, deg. B.T.C.	25	25	25
Exhaust pressure, in. Hg abs.	29.4	29.3 ±0.3	29 ±0.3 and 15
Cylinder temperature at rear spark-plug boss, °F	470	440 or varied	Varied
Cooling-air pressure drop, $\sigma\Delta p$, in. water	Varied	Varied	Varied
Compression ratio	6.7	6.7	6.7

The flight knock tests were conducted to compare knock data obtained with constant cowl-flap setting and constant cylinder temperatures.

RESULTS AND DISCUSSION

Static valve-lift diagrams. - Static valve-lift diagrams are presented in figure 3 for the single-cylinder and multicylinder engines with 0.000-inch valve clearance and with valve clearances that give valve timing close to that specified by the engine manufacturer. The effect of valve clearance on valve overlap (both valves at same clearance), geometric compression ratio, and geometric expansion ratio (ratios determined from the piston position when the intake valve closes and when the exhaust valve opens, respectively) are shown in figure 4. The data in figure 3 show that the running valve clearance for the single-cylinder engine should be about 0.105 inch in order to simulate the valve timing specified for the multicylinder engine.

Running valve-lift diagrams. - When the single-cylinder engine is started and brought to operating temperatures, the changes in valve clearances that occur are probably different from those of the multicylinder engine. Even if the valve-clearance changes were the same for the single-cylinder and the multicylinder engines, figure 4 shows that the valve overlaps, geometric compression ratios, and geometric expansion ratios would be different. The foregoing considerations indicate that running valve-lift diagrams are necessary in order to determine the running valve timing of these engines. Running valve-lift diagrams of the single-cylinder engine were obtained in order to determine cold valve clearances that produce running valve timing as specified for the multicylinder engine.

A comparison is made in figure 5 of running valve-lift diagrams obtained with the single-cylinder engine and static valve-lift diagrams with the multicylinder engine (fig. 3) for valve clearances that give the valve timing as specified by the engine manufacturer. The diagram for the single-cylinder engine operating with 0.010-inch cold clearances (specified by the manufacturer) deviates considerably from the static diagram for the multicylinder engine. The deviations during the opening and closing of the valves and the high lift are sufficient to affect the scavenging of the cylinder and the engine performance. When the cold clearances were changed to 0.090 inch for the intake valve and 0.060 inch for the exhaust valve, the running valve-lift diagrams obtained agreed favorably with the static diagrams for the multicylinder engine.

Effect of valve clearance on knock-limited performance. - Single-cylinder-engine knock and cooling data, with the valve clearances for the valve-lift diagrams presented in figure 5, are compared in figures 6 and 7 with multicylinder-engine flight knock and cooling data. The large valve clearances reduced the knock-limited charge-air flow of the single-cylinder engine as much as 26 percent at a fuel-air ratio of 0.065 and 9.5 percent at a fuel-air ratio of 0.10. The knock-limited and cooling performance of the single-cylinder and multicylinder engines matched when cold valve clearances were used that gave running valve-lift diagrams similar to the static diagrams for the multicylinder engine. The knock-limited indicated mean effective pressure (fig. 6) for the multicylinder engine was estimated on the basis of 83-percent mechanical efficiency. That the knock-limited charge-air flows matched and the inlet-air pressures did not should be noted. The difference in temperatures of the single-cylinder engine and the multicylinder engine, shown in figure 7, would have no great effect on the knock-limited performances.

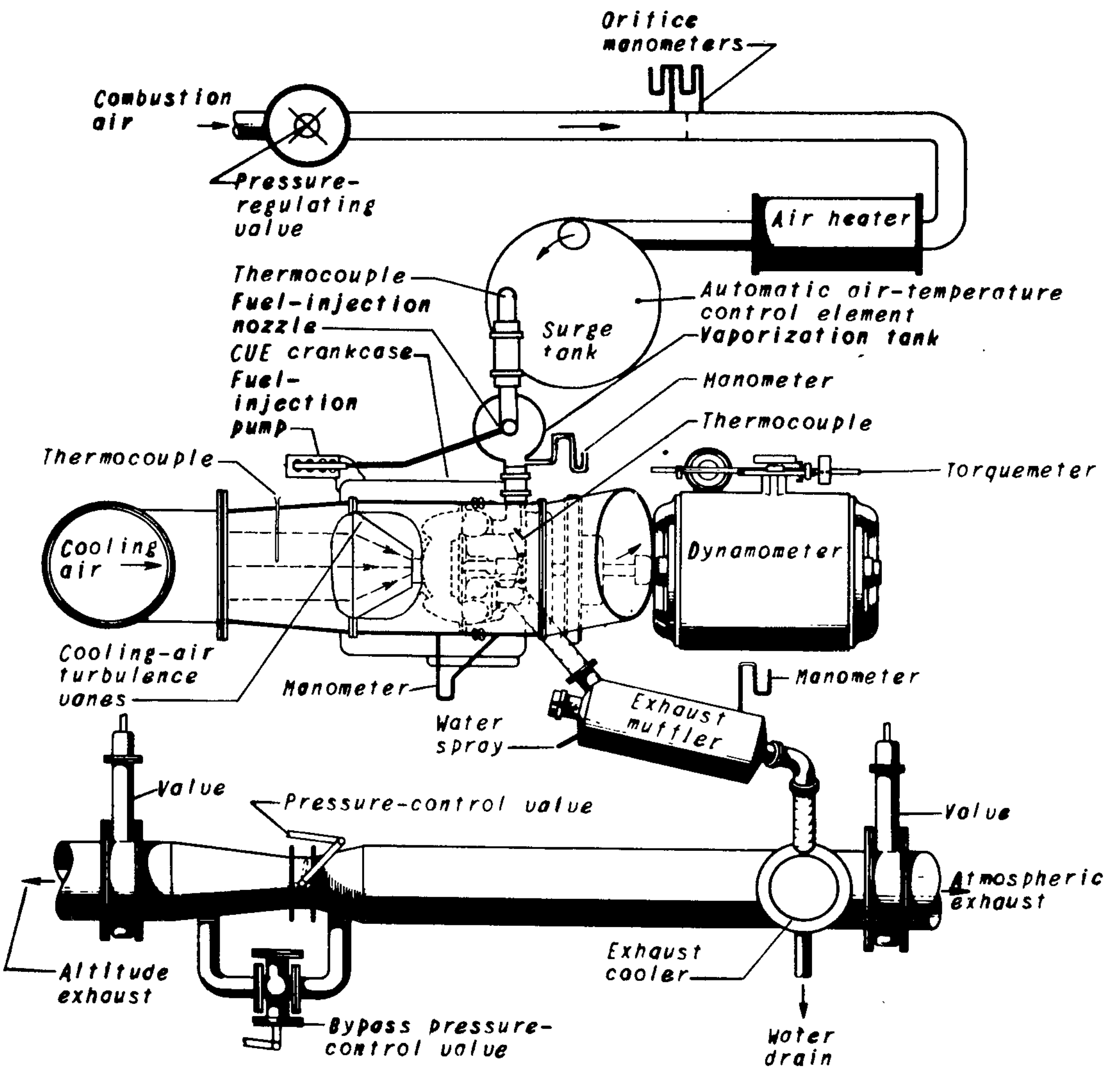

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Figure 1. - Single-cylinder setup.

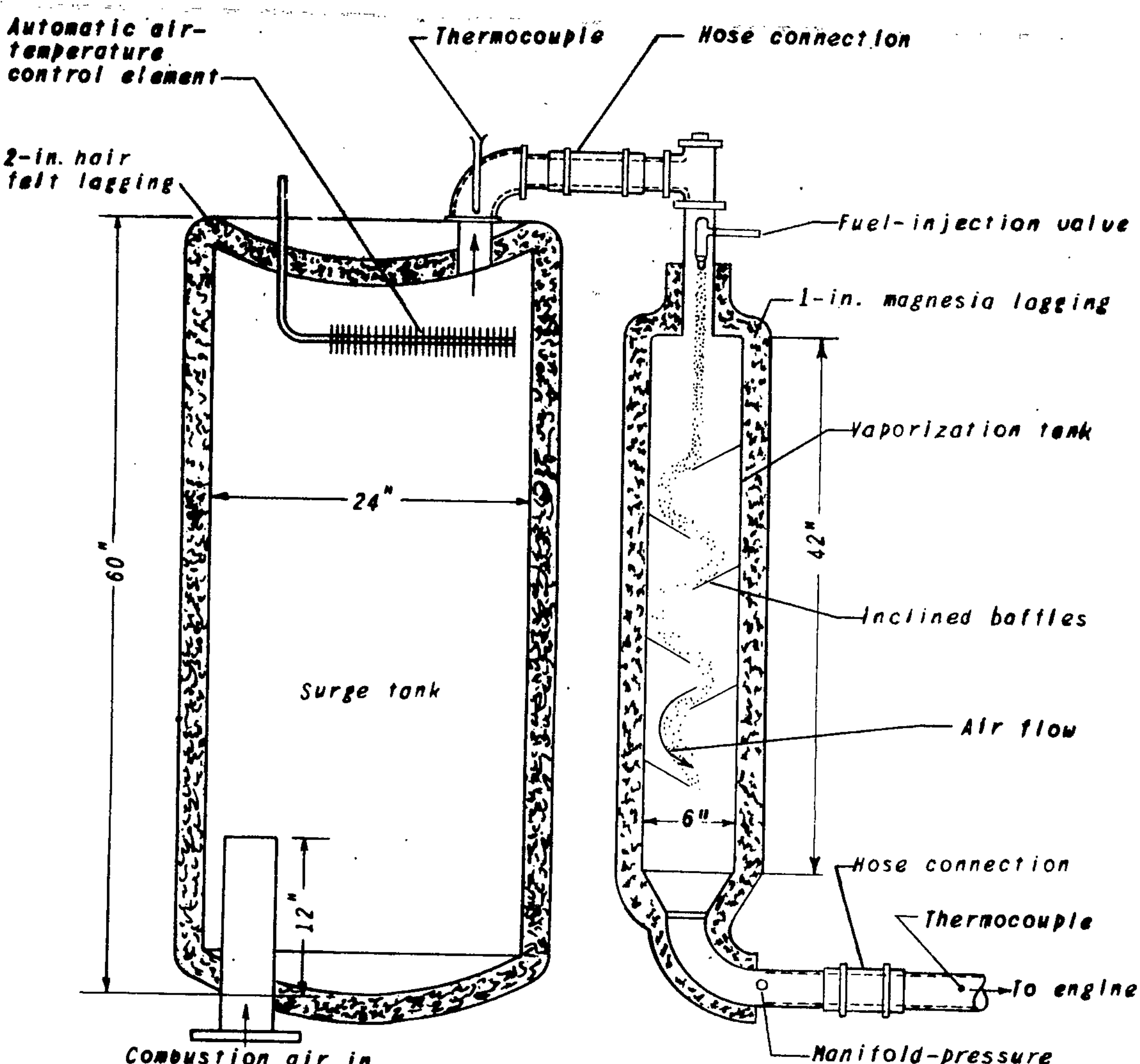

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Figure 2. - Induction system used with single-cylinder setup.

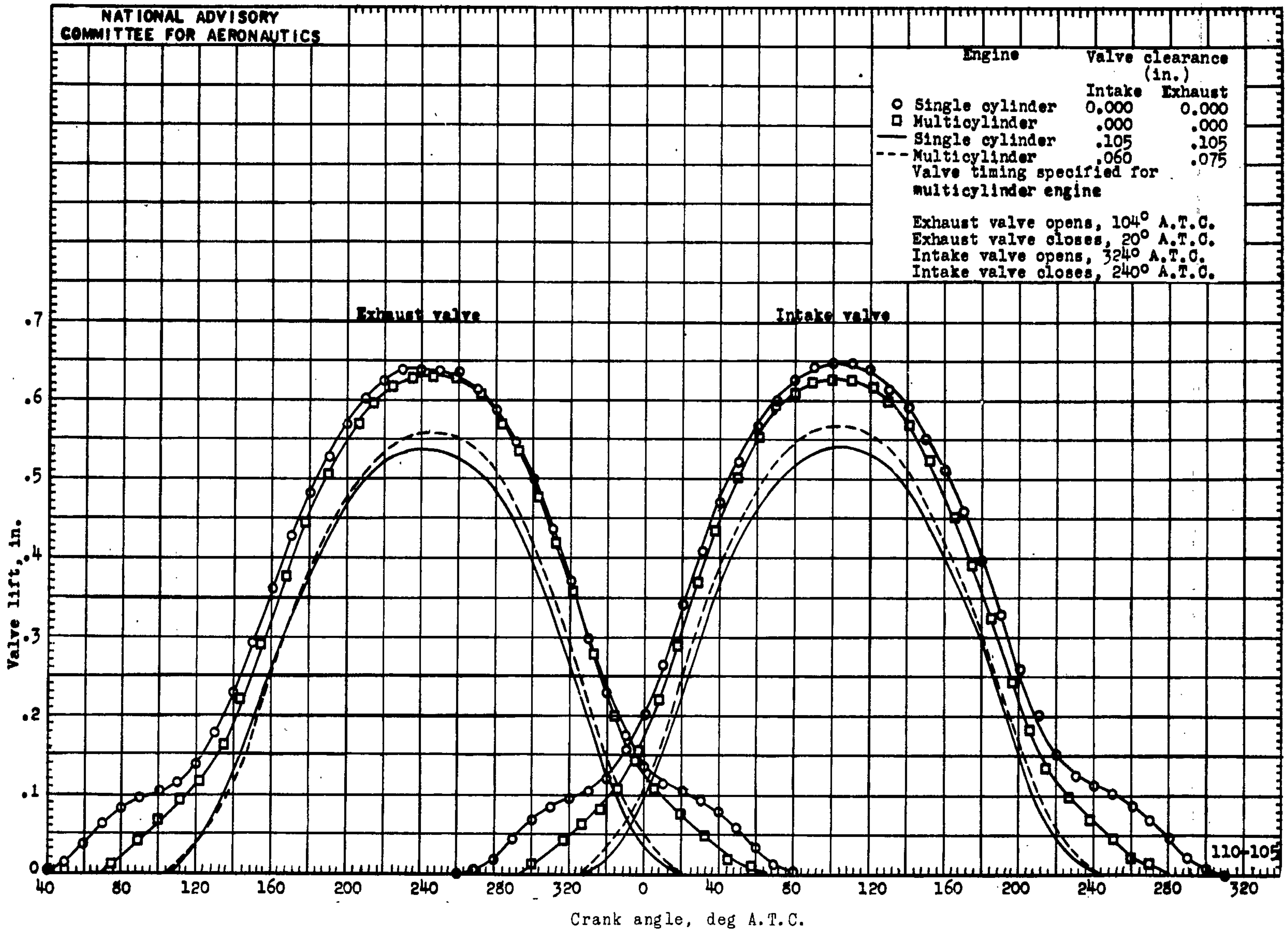

Figure 3. - Static valve-lift diagrams of a single cylinder and a multicylinder engine (dial-indicator reading, engine not running).

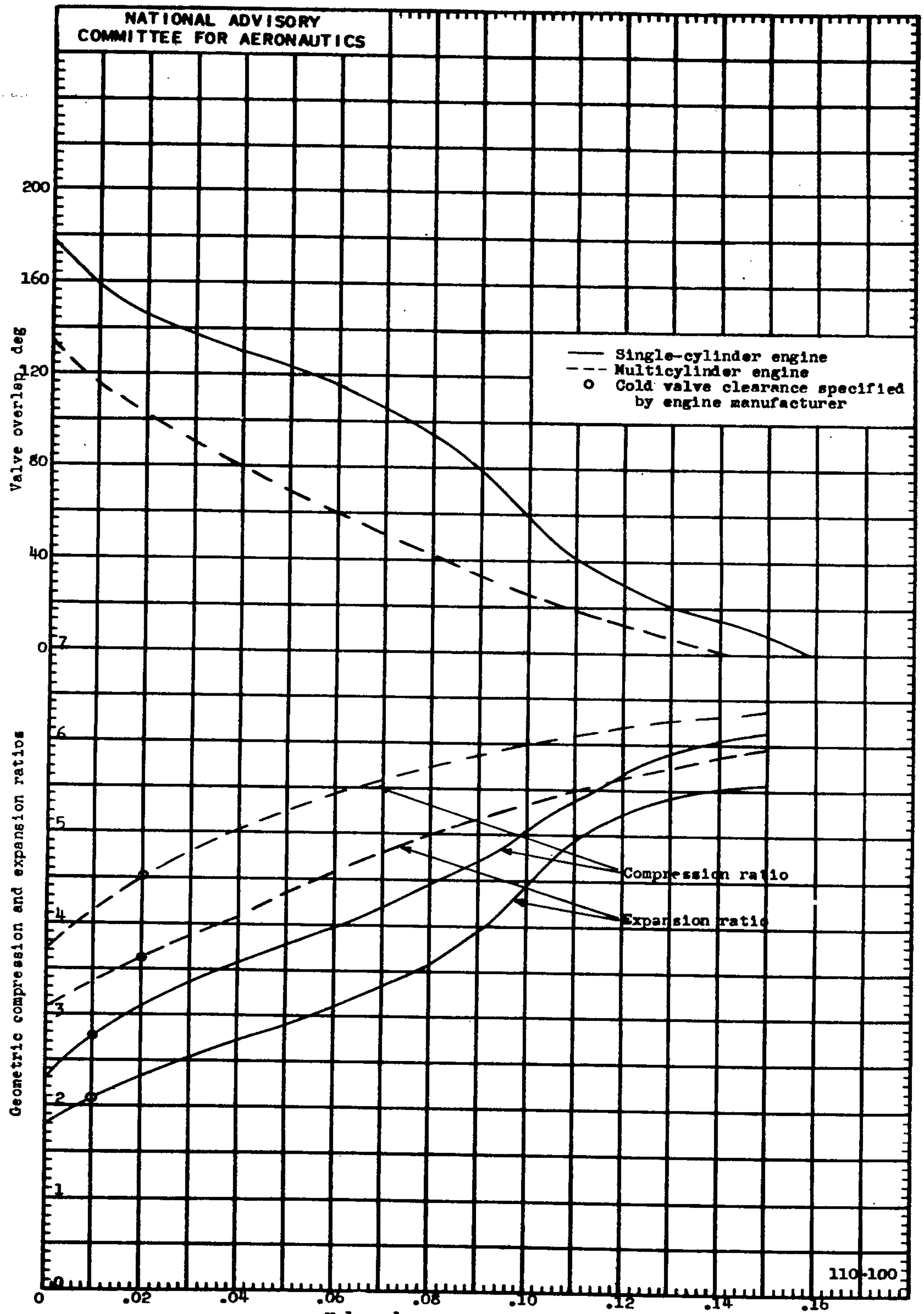

Figure 4. - Effect of valve clearance on valve overlap (both valves at same clearance), geometric compression ratio, and geometric expansion ratio (ratios determined from the piston position when intake valve closes and when exhaust valve opens, respectively). Cross plot of figure 3.

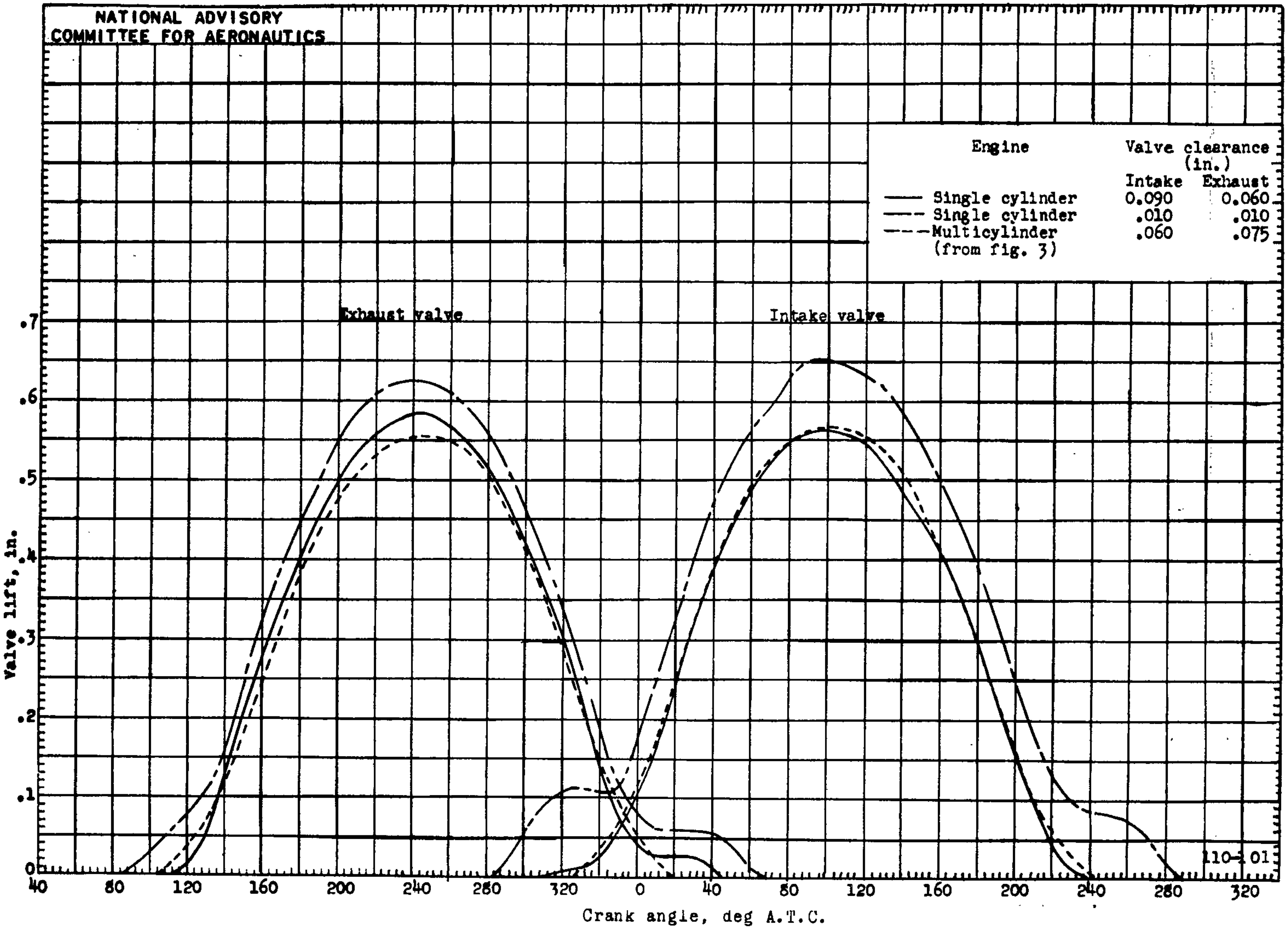

Figure 5. - Comparison of running valve-lift diagrams of a single cylinder on a CUE crankcase and static valve-lift diagrams of a multicylinder engine. Engine speed, 2250 rpm; inlet-air pressure, 36 inches of mercury absolute; inlet-air temperature, 210° F; fuel-air ratio, 0.075; mixture temperature, 150° F; exhaust pressure, 29.4 inches of mercury absolute; rear-spark-plug temperature, 470° F; spark advance, 25° B.T.C. (both plugs); compression ratio, 6.7; fuel, 28-R

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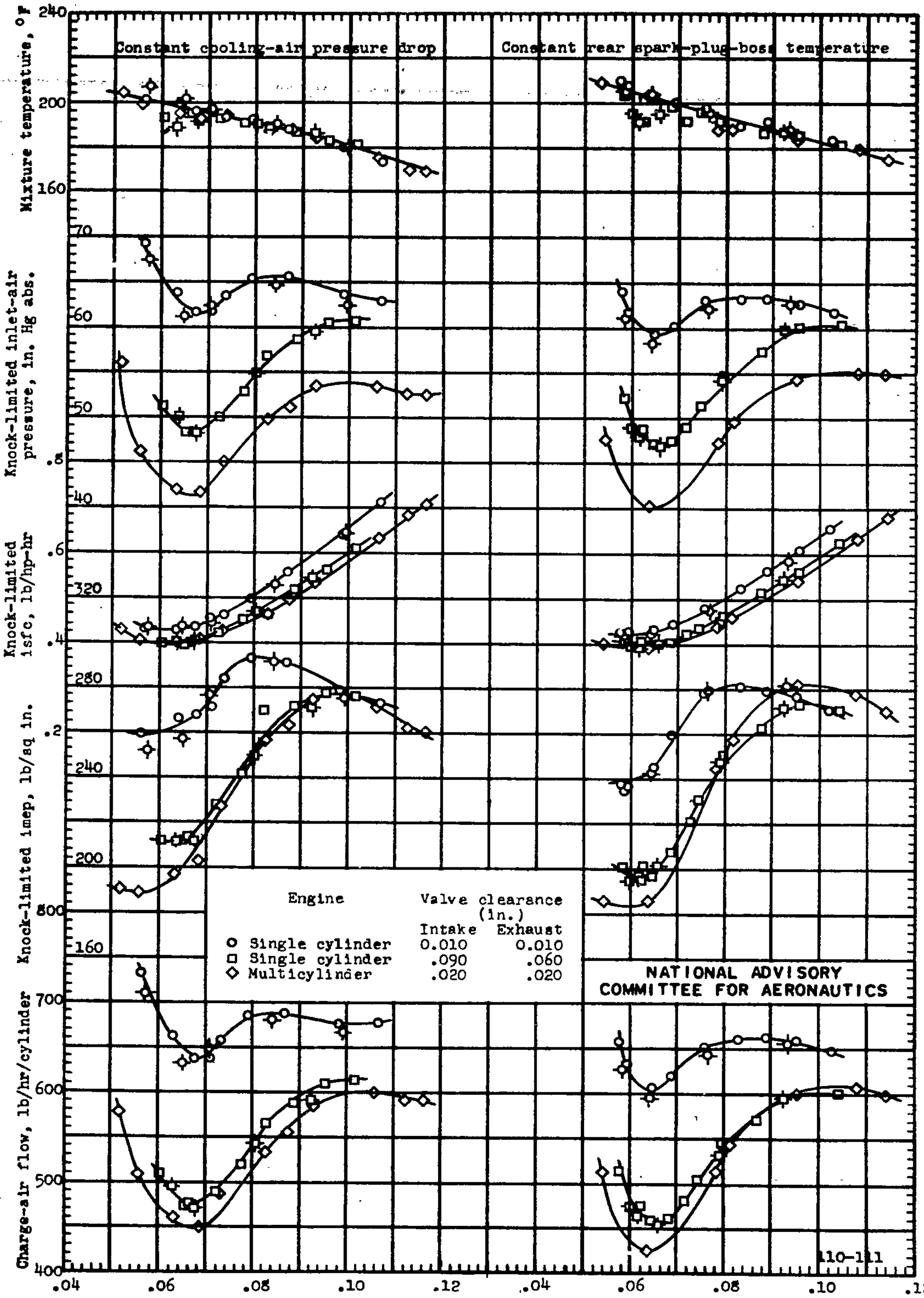


Figure 6. - Knock-limited performance of a multicylinder engine and a single cylinder on a CUE crankcase with several cold valve clearances. Engine speed, 2250 rpm; spark advance, 25° B.T.C. (both plugs); compression ratio, 6.7; fuel, 28-R.

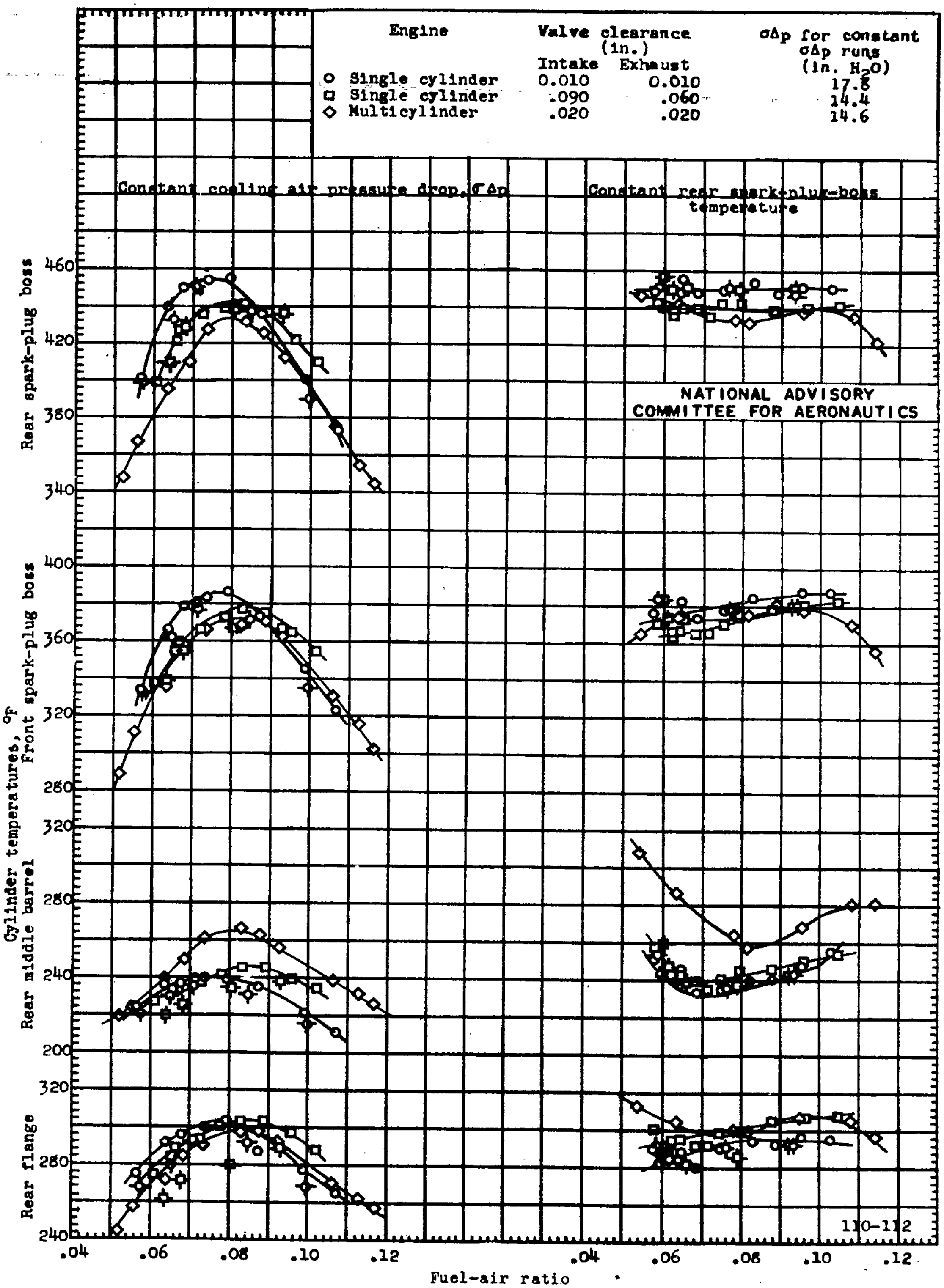
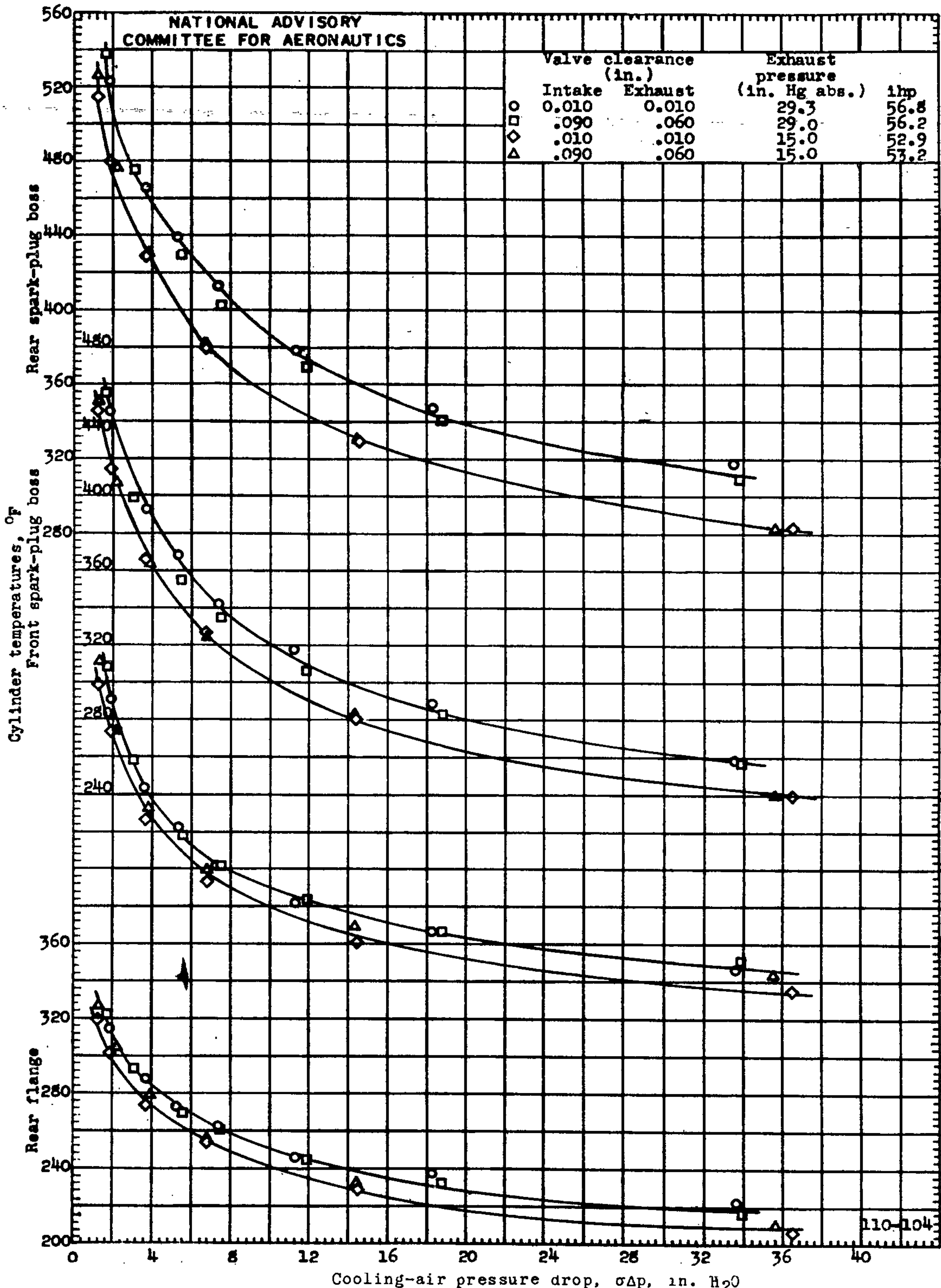
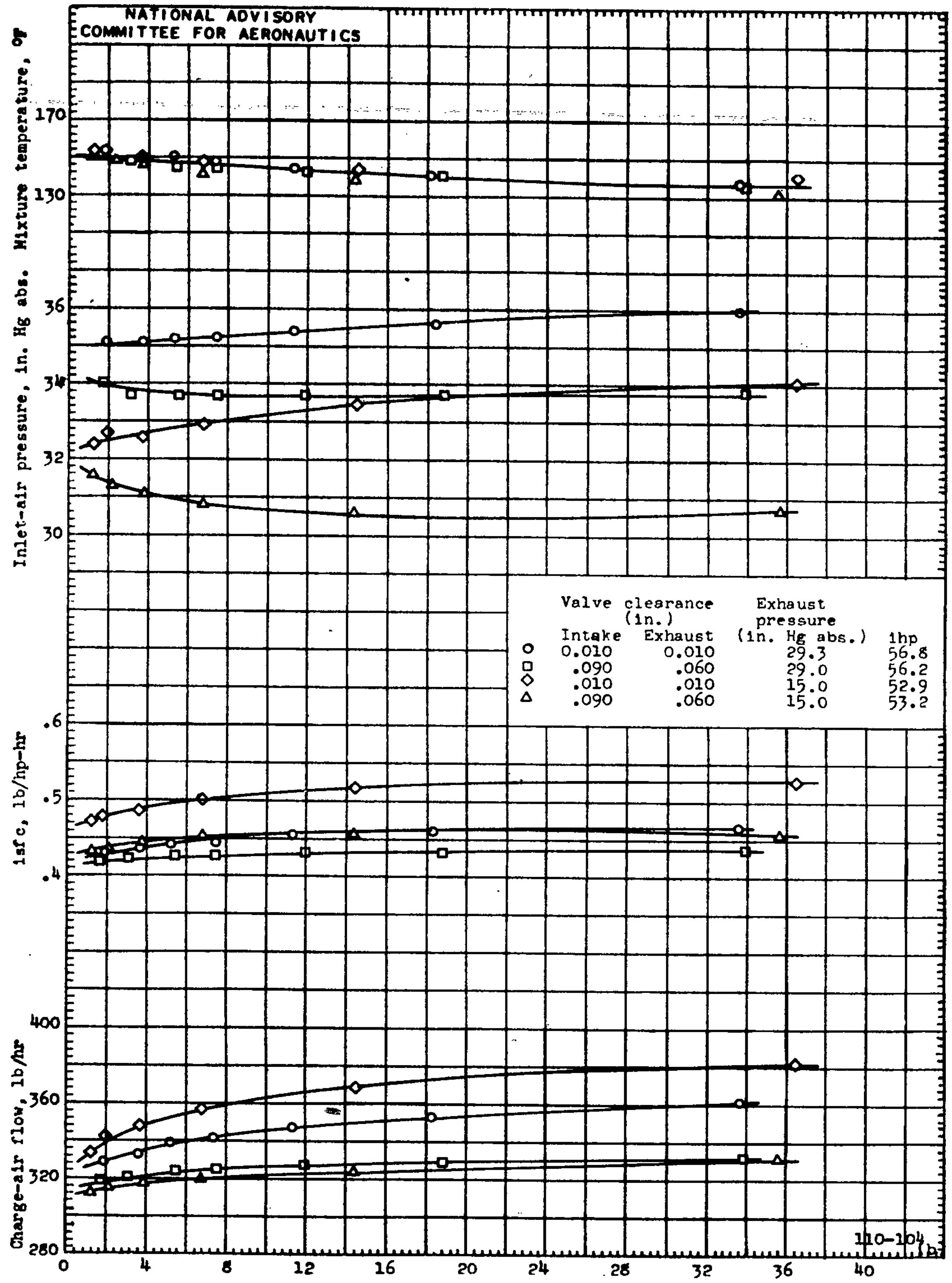


Figure 7. - Engine temperatures at knock-limited performance of a multicylinder engine and a single cylinder on a CUE crankcase with several cold valve clearances. Engine speed, 2250 rpm; spark advance, 25° B.T.C. (both plugs); compression ratio, 6.7; fuel, 28-R.



(a) Cylinder temperatures.

Figure 8. - Performance of a single cylinder in cooling tests with several cold valve clearances. Engine speed, 2250 rpm; inlet-air temperature, 210° F; fuel-air ratio, 0.075; spark advance, 25° B.T.C. (both plugs); compression ratio, 6.7; fuel, 28-R.



(b) Mixture temperature, inlet-air pressure, indicated specific fuel consumption, and charge-air flow.

Figure 8. - Concluded. Performance of a single cylinder in cooling tests with several cold valve clearances. Engine speed, 2250 rpm; inlet-air temperature, 210° F; fuel-air ratio, 0.075; spark advance, 25° B.T.C. (both plugs); compression ratio, 6.7; fuel, 28-R.

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